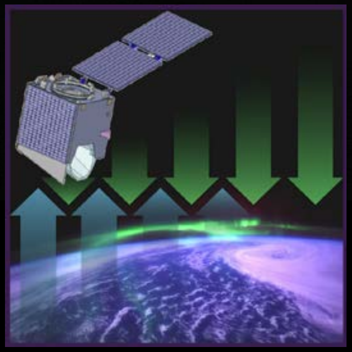
LINKING OBSERVATIONS OF CLIMATE, THE UPPER ATMOSPHERE AND SPACE WEATHER

LOCUS

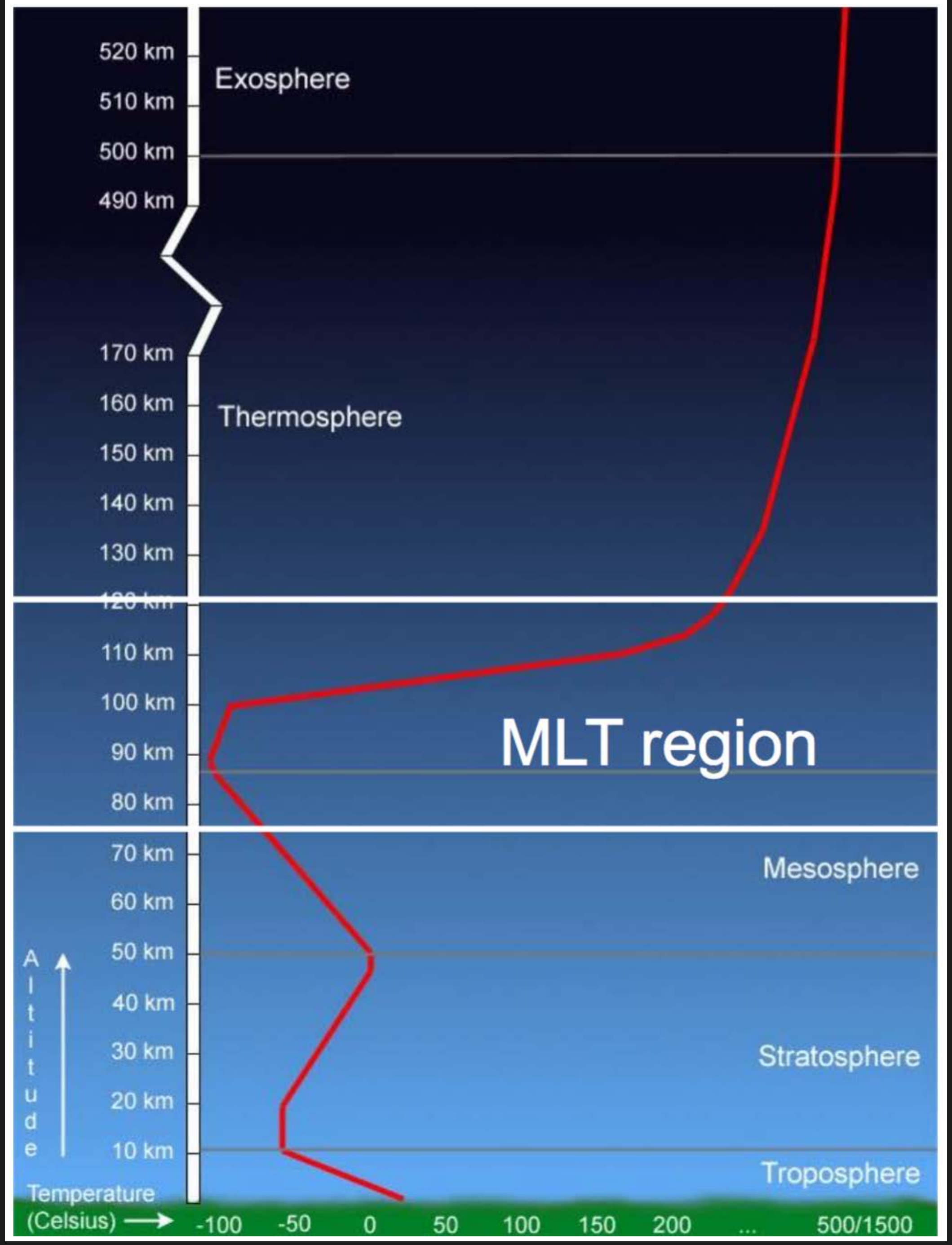


LOCUS IN A NUTSHELL

- Proposal for a satellite to target the Mesosphere — Lower Thermosphere region (MLT)
- International consortium evolved from a UK core team
- ESA EE-10 candidate mission

MESOSPHERE - LOWER THERMOSPHERE REGION

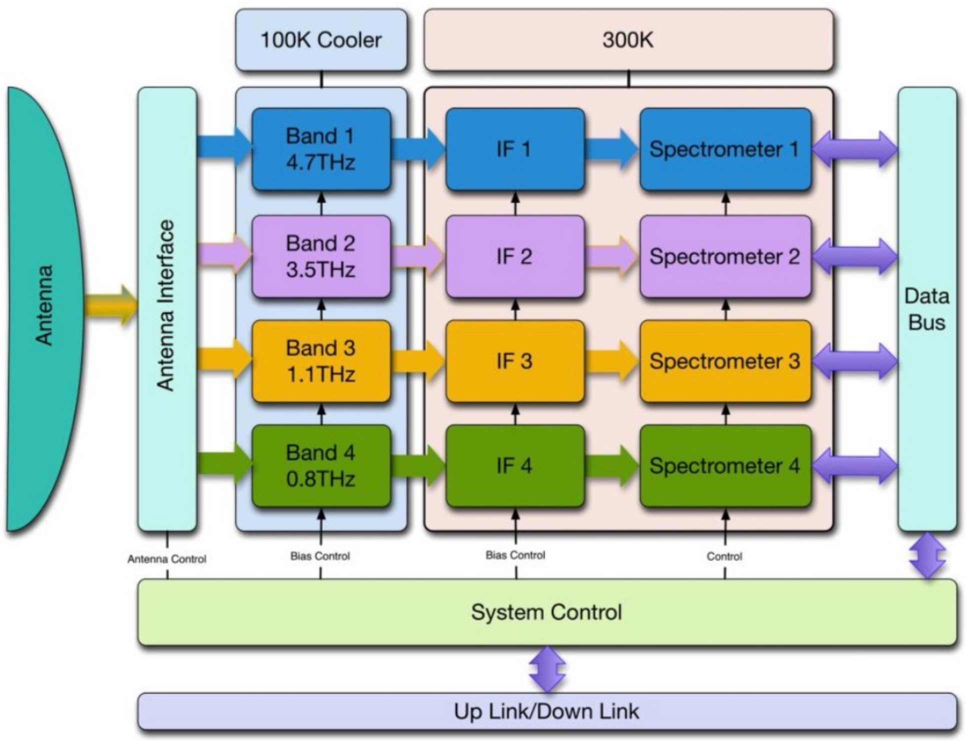
- Interface between Atmosphere and Space
- Indicative of climate change through:
  - Increased cooling rates
    Beig et al., JGR, 2011
  - Increase of mesospheric clouds DeLand et al., JGR, 2015
- Not well explored, because it is:
  - Too high for balloons; too low for orbiters
  - Many key species only detectable at THz frequencies, e.g. atomic oxygen (O) and OH



LOCUS INSTRUMENT CONCEPT

- 4 THz Bands: Direct detection of the abundance of key MLT species
- 5 Infrared Channels: Measuring thermal emissions, Temperature, and SABER method for indirect O

THz Band	Centre [THz]	Width [GHz]	Science Targets	Noise [K]
1	4.7	1	O	46
2	3.5	2	OH, HO_2	12
3	1.1	2	NO, CO, O_3 H_2O, NO^+	4
4	0.8	1	O_2, O_3	3



Infrared Channel	Centre [μm]	Width [μm]	Science Target	Detectab. [$Wm^{-2}sr^{-1}$]
1	15.2	2.5	CO_2	1E-03
2	14.9	5.27	CO_2	1E-03
3	9.6	1.75	O_3	3E-04
4	5.3	0.41	NO	1E-05
5	4.3	0.23	CO_2	1E-05

SCIENCE OBJECTIVES

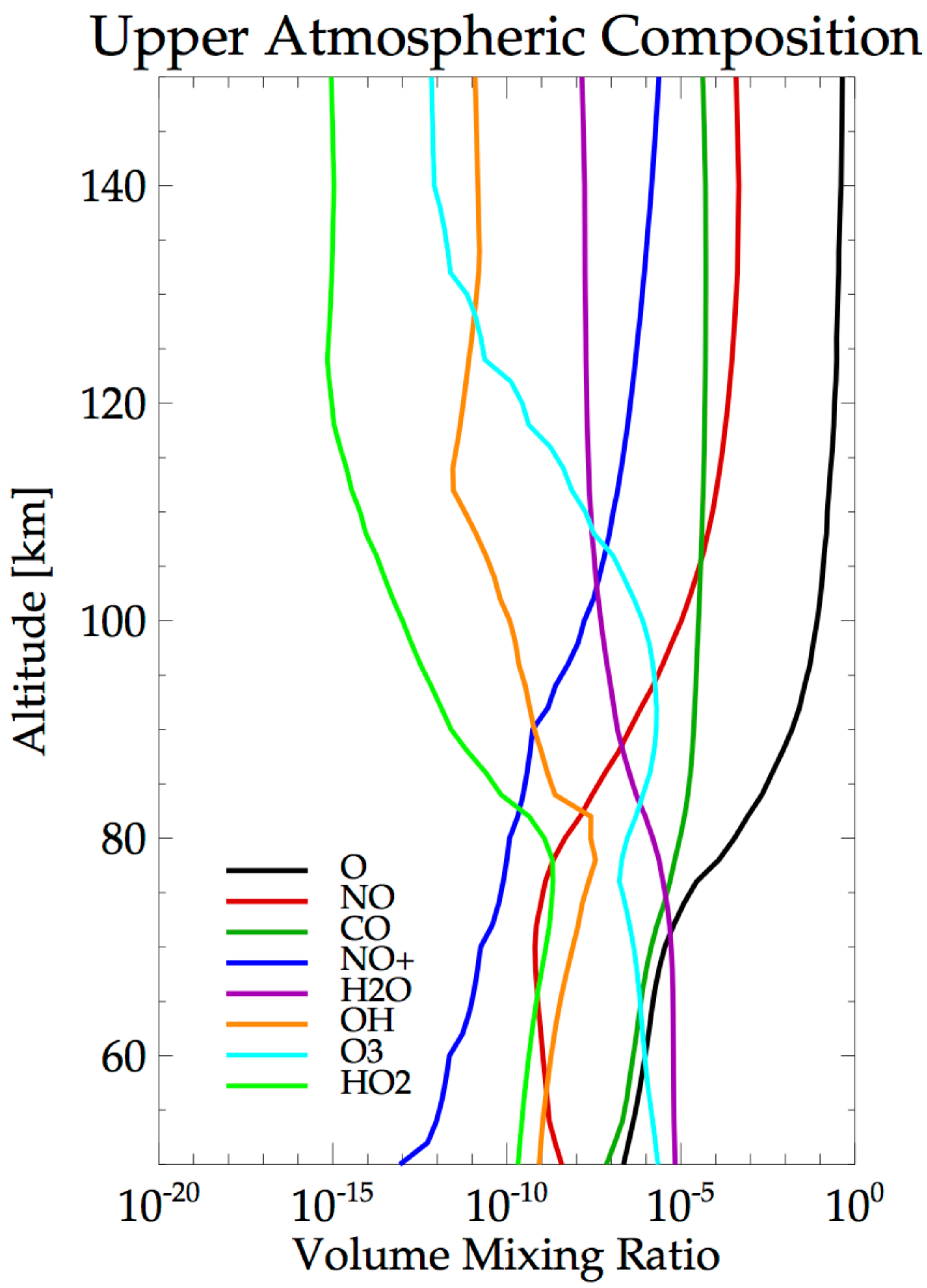
- Energy Balance
- Noctilucent Clouds
- Auroral Forcing
- Improved Climate and Weather Prediction Models

SCIENCE MOTIVATION

- Climate
- Space Weather

ENERGY BALANCE

- O dominates thermal balance of MLT through collisional excitation of CO_2 (15µm), NO (5.3µm) and self-emission at 63µm
- Observed cooling is offset by stratospheric ozone and GHG, but by how much?
- Composition measurements needed to understand MLT cooling trend observed by other techniques



NOCTILUCENT CLOUDS

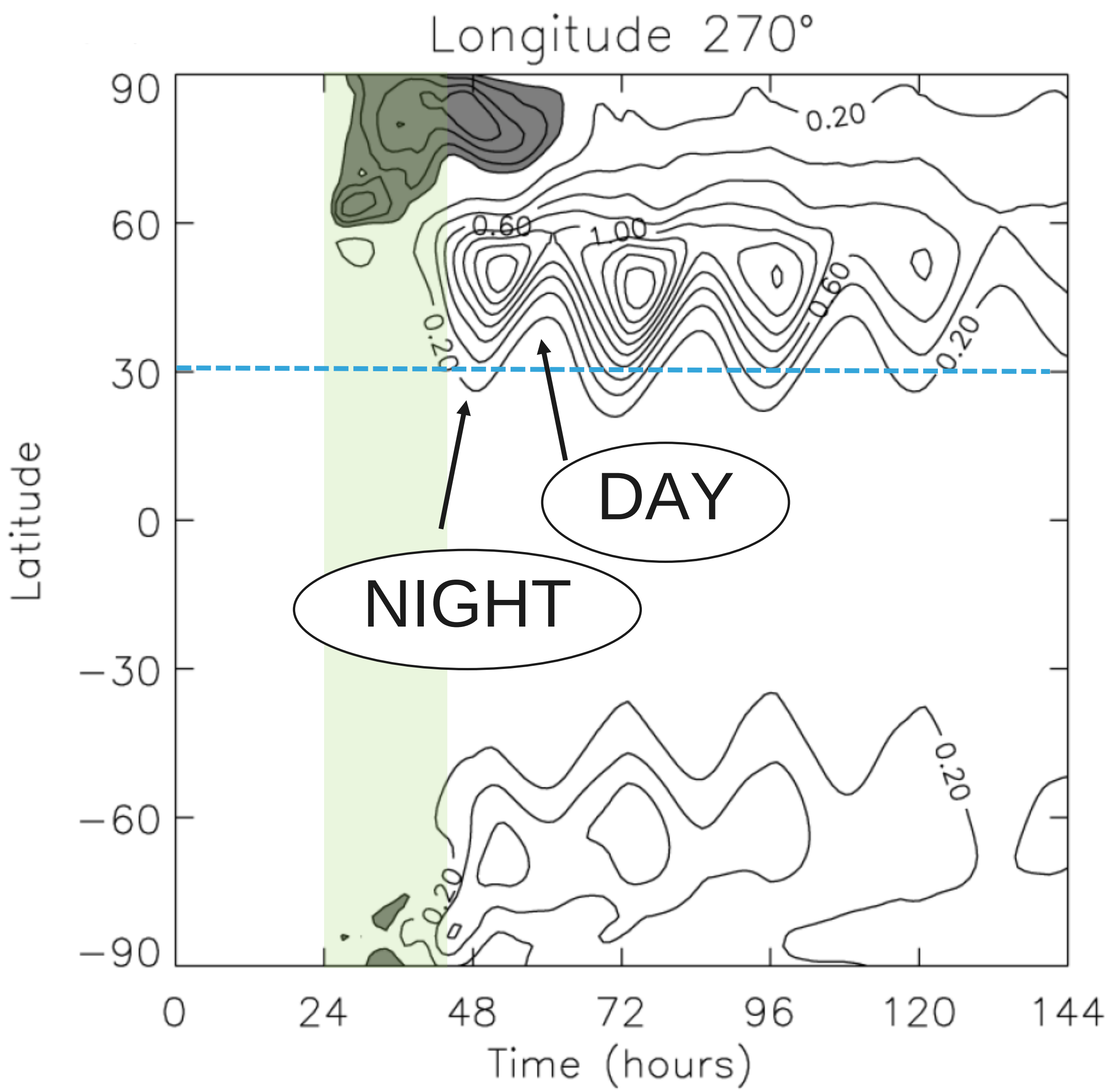
- Localised phenomenon at high latitudes and narrow altitude range
- Increased frequency and intensity of NLC observed from ground Russell et al., JGR, 2104
- Formation governed by humidity and temperature (climate proxy) Thomas et al., ASR, 2001
- H_2O and temperature measured by LOCUS in campaign mode

AURORAL FORCING

- The Aurora (interaction of solar wind with the atmosphere) drives the NO concentration and thus the thermal balance

- Downwelling of NO through mean meridional circulation drives the stratospheric O_3 chemistry
  Fytterer et al., ACP, 2015

- Enhanced ionospheric NO^+ affects satellite- and tele-communication



Courtesy A. Aylward, UCL

IMPROVED ATMOSPHERIC MODELS

- Trend is towards *whole atmosphere models*, and eventually sun-earth models

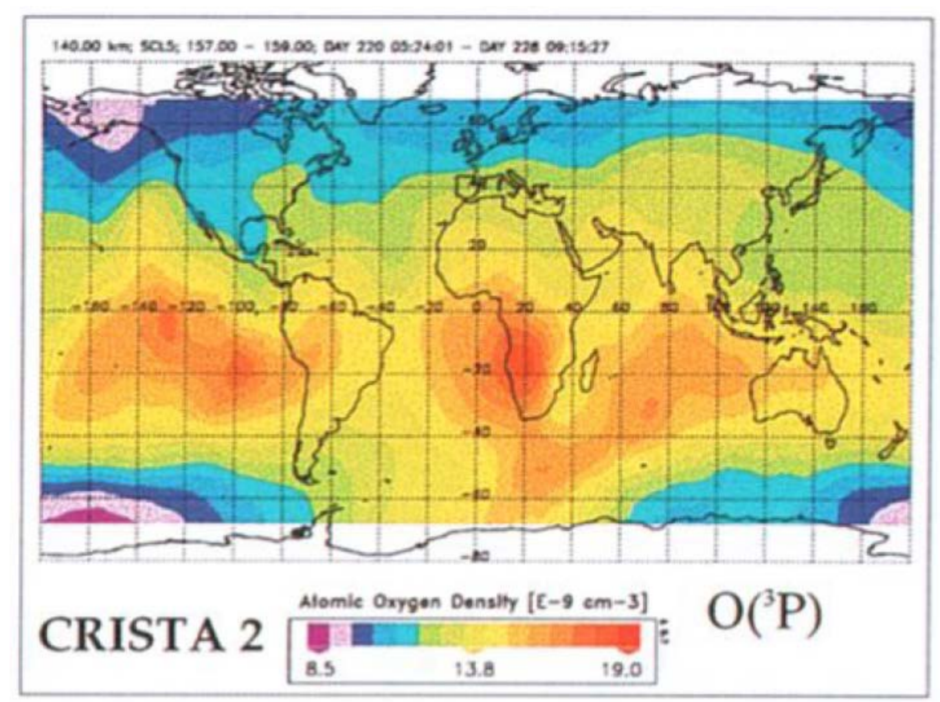
  Liu et al., JGR, 2010

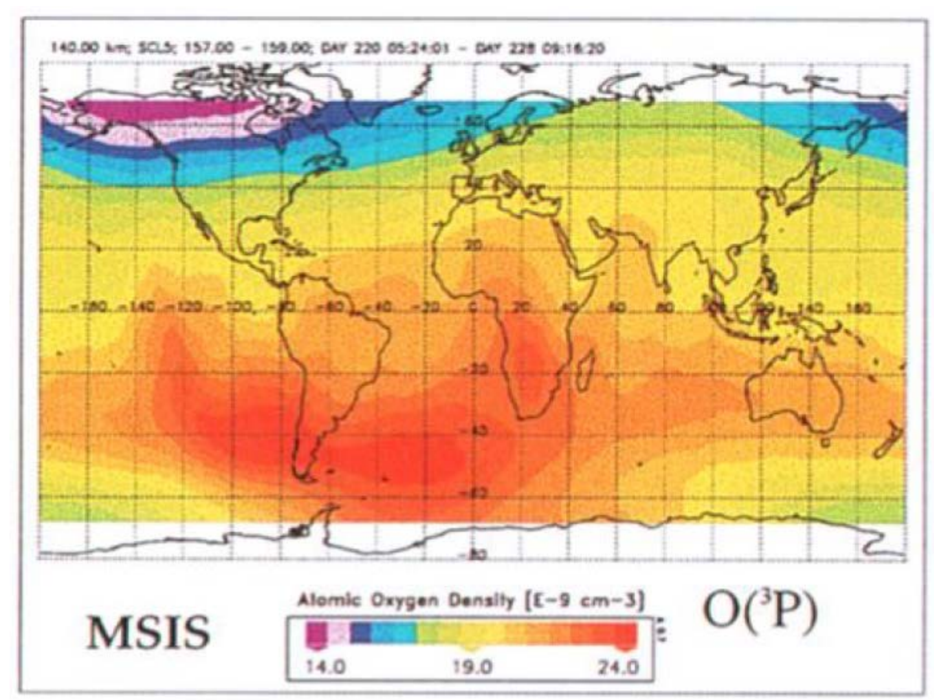
- Assimilated MLT measurements improve surface NWP (seasonal)
  Hoppel et al., ACP, 2008

- Space weather moved up on the national risk registers

"DELTA SCIENCE" FROM LOCUS

- Sparce data, especially on O, due to absence of high spectral resolution heterodyne detectors at THz frequencies ("THz Gap")
- CRISTA: First direct detection of 63μm O line from two Space Shuttle missions (grating spectrometer)
  Grossmann et al., GRL, 2000
- MLS: 2.5 THz channel for OH and HO_2 (optically pumped THz detector with gas-laser LO)
  Mueller et al., OSA, 2007
- SABER: Indirect method to estimate O from IR channels (uncertainties from assumptions on reaction rates)
  Mlynczak et al., JGR, 2013





Grossmann, GRL, 2000

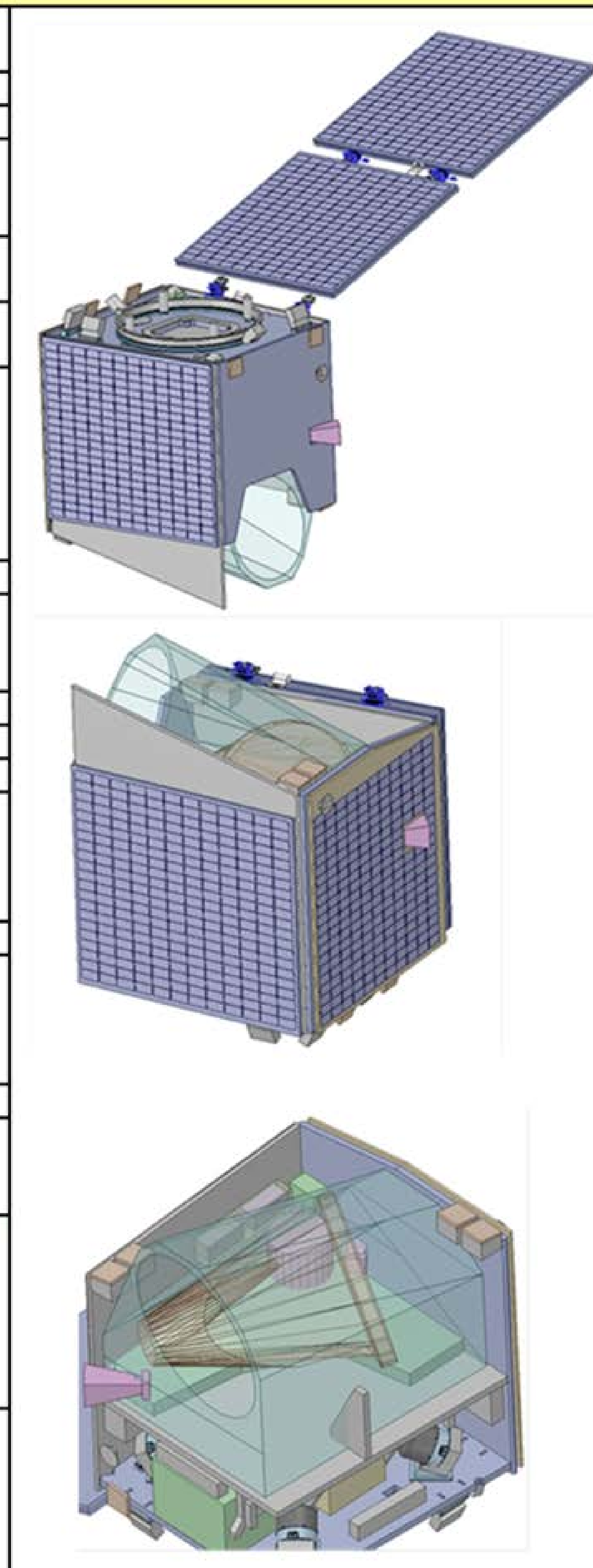
NOVELTY OF THE LOCUS MISSION CONCEPT

- Combination of THz and IR sensors for:
  - Direct abundance measurements of key MLT species O, OH, NO/NO^+, CO, HO_2, H_2O, O_3, O_2
  - Measuring thermal emission rates (CO_2, NO), temperature profiling, and indirect detection of O
- Quantum Cascade Laser (QCL) LO to bridge THz gap

LOCUS SATELLITE DESIGN

- Mission concept developed in ESA In Orbit Demonstration Study in 2014
- Compatible with small satellite platforms
- Along track scanning LEO sounder with campaign modes for
  - Composition and thermal balance
  - Auroral forcing
  - Noctilucent clouds

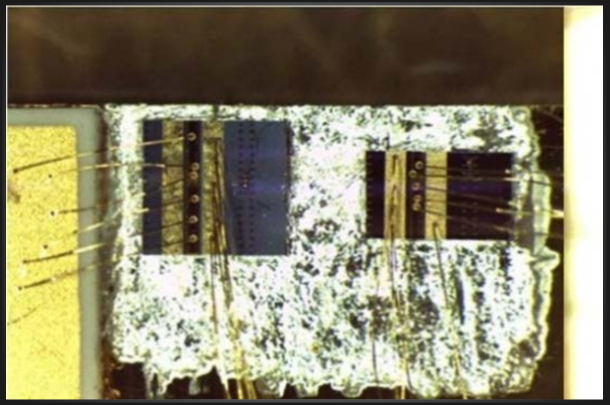
Platform and Payload Characteristics	
Dry mass	262.3 kg
Propellant mass	12 kg
3-axis stabilised	
Interface	2 x AIM
Sensors	2 x Star Tracker 3 x Sun Sensor 2 x GPS reciever
Actuators	4 x Reaction wheels 3 x Magnetorquers
Propulsion	1 x µQCT 1 x Xenon tank
Solar Arrays	Solar Cells: 27.5% 3J GaAs 2 x Body mounted panels 2 x Deployed panels 4 x Hinge 2 x HDRM OAP: 194W
Battery	1 x 15Ah Li-Ion
Conditioning	2 x BCM 1 x PDM 28V unregulated bus
OBC	2 x OBC386
Data Storage	2 x HSDR
Interface	2 x PIU
S-band	2 x High Rate Tx (4 Mbps) 2 x Low rate Tx/Rx (19/38 kbps) 8 x Patch Antenna 2 x Monopole Antenna
MLI,heaters, thermistors, FSM, SSM, tapes etc.	
Aluminium honeycomb panels Microtray stack Support struts 610mm launch adapter ring	
Mounting	Optical Bench
Antenna	Primary mirror Secondary mirror Calibration flip mirror
Radiometer	2 x Integrated QCL & diode mixer 2 x Conventional diode mixer 4 x IF stage 4 x Wide band spectrometers 1 x Reciever housing 4 x IR detectors
Thermal	Hot radiator & heater Cold radiator 2 x Small cryo coolers MLI thermal tent MLT reciever tent ML cooler tent

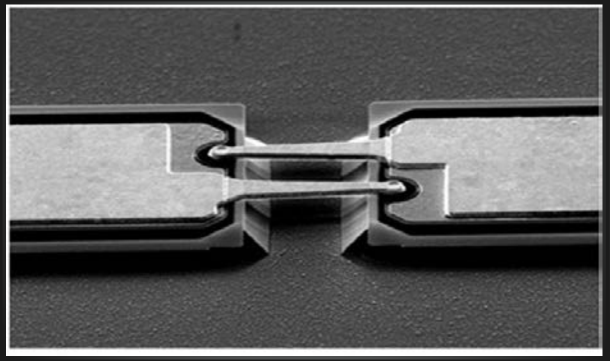


Courtesy SSTL, ESA IOD Final Report, 2014

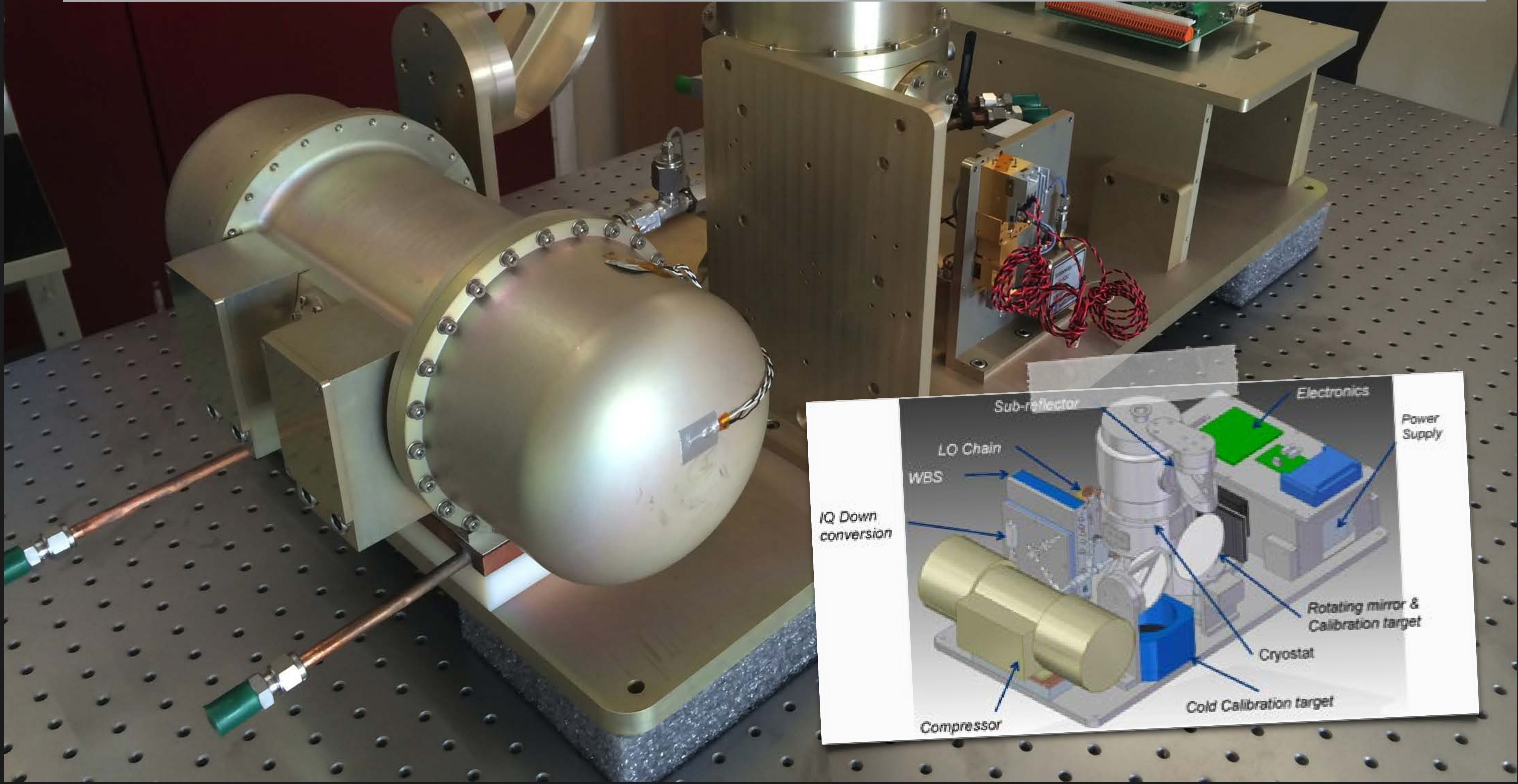
KEY TECHNOLOGIES

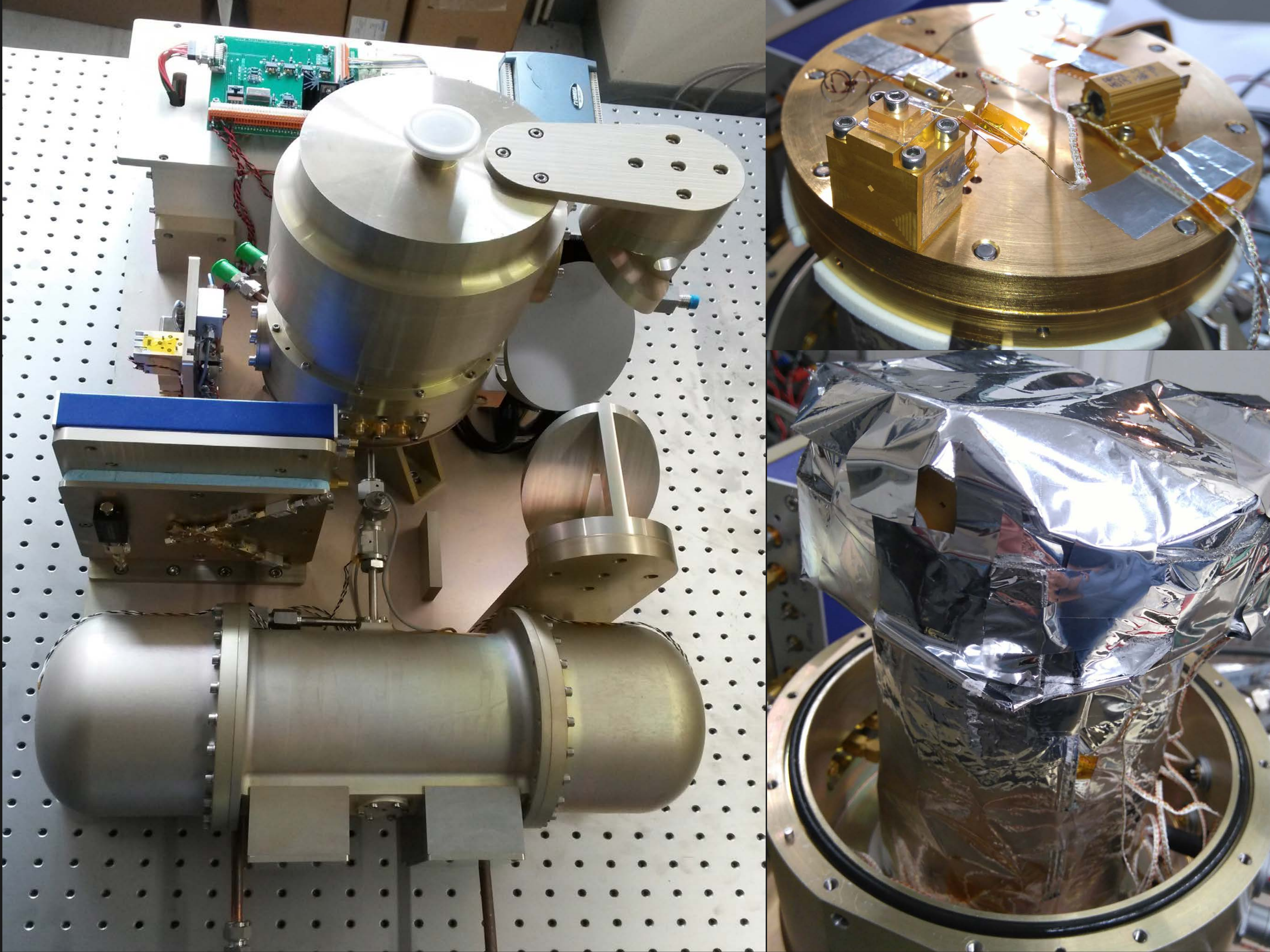
- Quantum Cascade Laser (QCL) provides Local Oscillator power *University of Leeds*
- Heterodyne frequency down-conversion (mixers) *RAL Space*
- Small scale active coolers required to cool down QCLs *RAL Technology*
- Wide band, high resolution spectrometer *STAR-Dundee*





LOCUS 1.14 THZ BREADBOARD





TARDIS – THE PORTAL TO SPACE FOR THZ TECHNOLOGY?

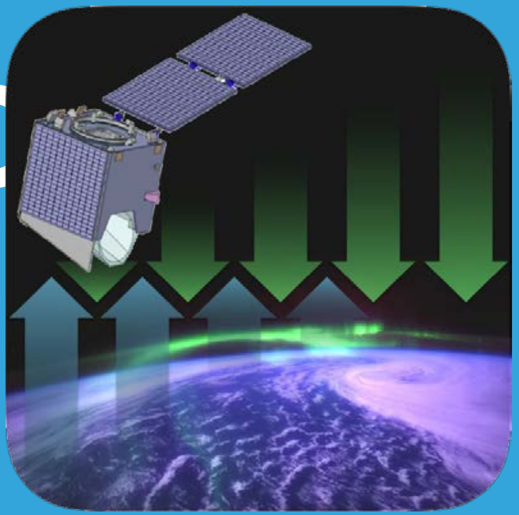
- Biggest problem for novel technologies is the ”TRL Valley of Death”
- TARDiS could be deployed by UK astronaut Tim Peake during his potential second trip to the International Space Station in 2020

SPARE SLIDES

TAKE HOME MESSAGE

- Targets a crucial knowledge gap (MLT)
- Global and multi-annual direct detection of MLT key species (Atomic Oxygen) to complement IR measurements
- Use of novel technology to breach a scientific barrier (THz radiometers with QCL-pumped Schottky mixers)
- Candidate mission for 10th Earth Explorer call

LOW COST UPP
ATMOSPHERE
SOUNDER



Original LOCUS Acronym

LINKING OBSERVATIONS OF CLIMATE, THE UPPER ATMOSPHERE AND SPACE WEATHER

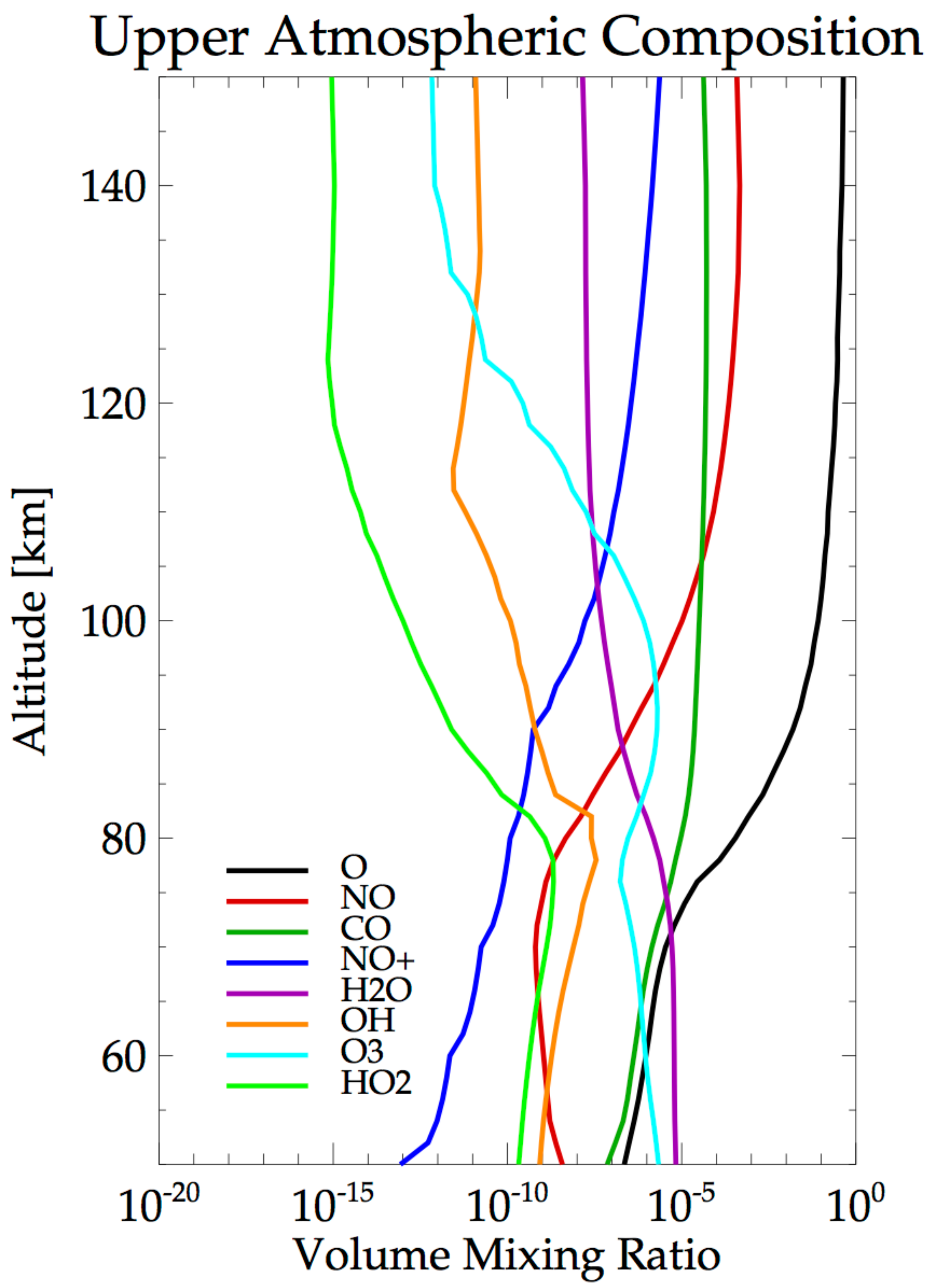
LOCUS

THE LOCUS MISSION CONCEPT

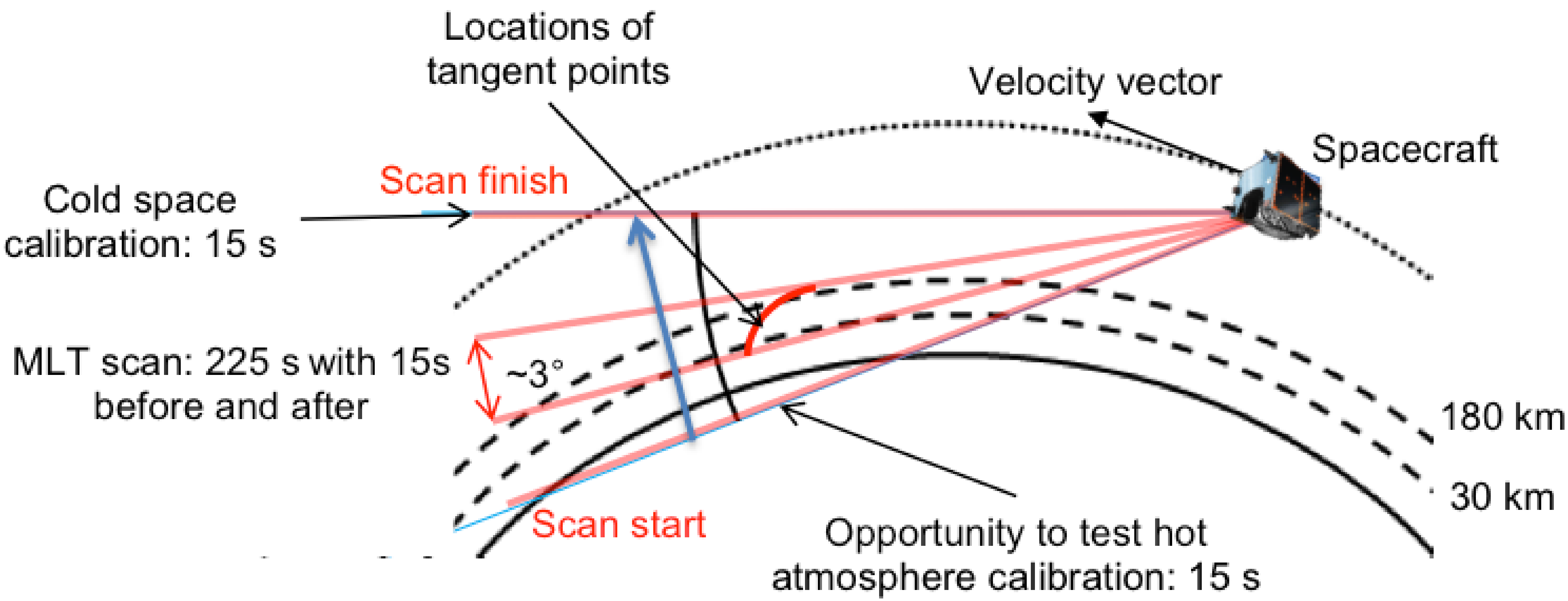
- Targets the Mesosphere - Lower Thermosphere (MLT)
- MLT altitude only accessible through remote sensing
- Many MLT key species only emit at THz frequencies
- THz heterodyne detectors are complex and expensive
- Quantum Cascade Laser (QCL) technology makes MLT accessible to Remote Sensing for the first time

LOCUS TARGET SPECIES (THZ BANDS)

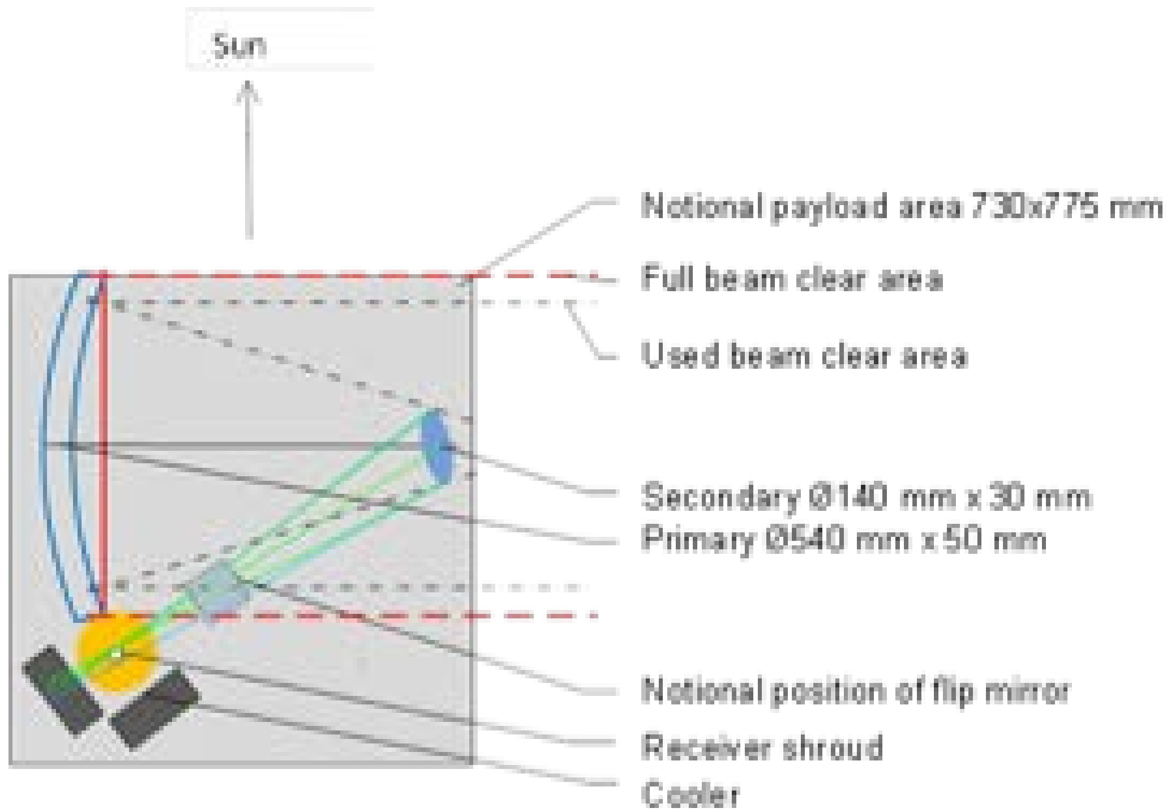
- O: MLT chemistry and radiative cooling
- OH: Mesospheric chemistry
- NO/NO+: Solar weather and radiative cooling
- CO: Mesospheric tracer
- H2O: Formation of mesospheric clouds
- O3: Anthropogenic chemistry and SABER method to calculate O (daytime)
- O2: Pointing and temperature profiling
- HO2: MLT chemistry

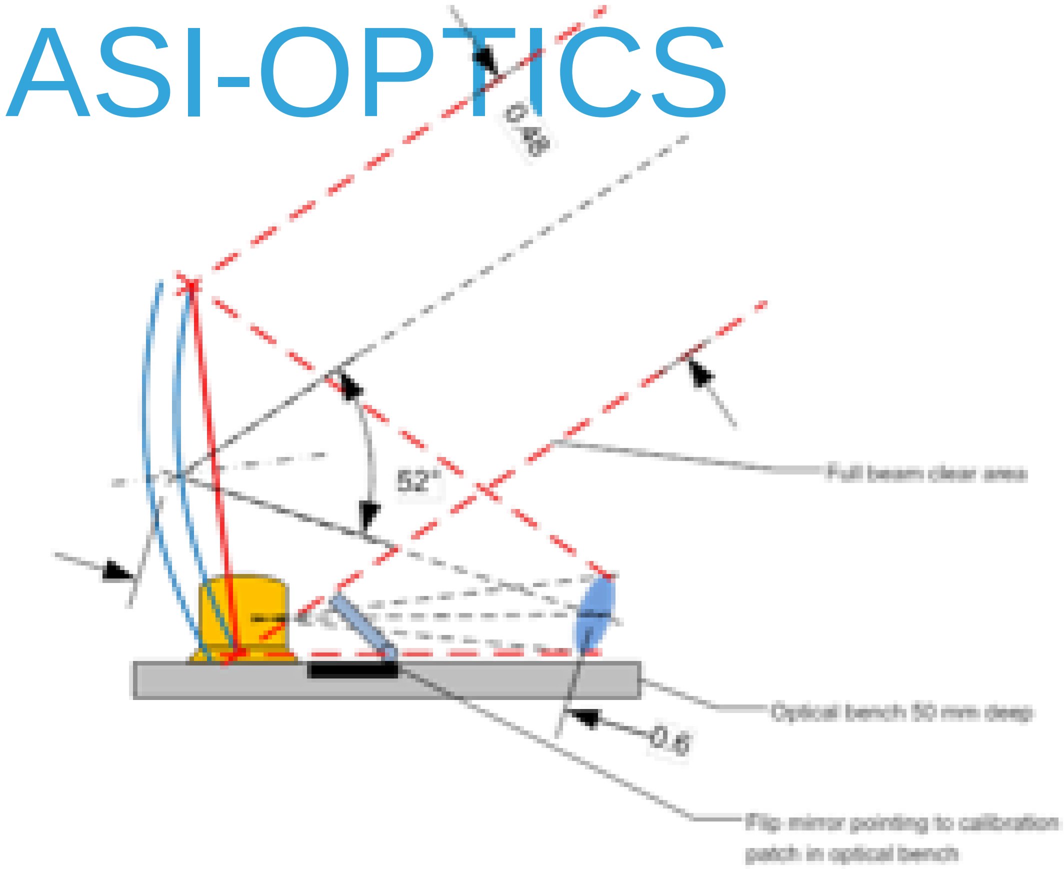


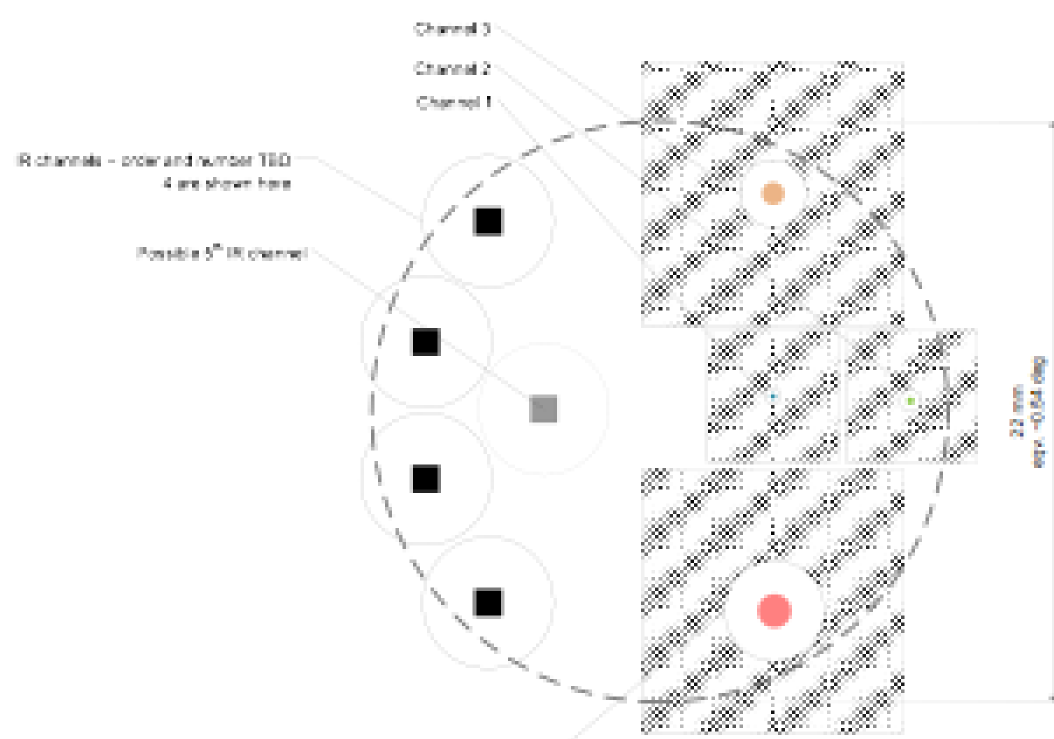
LOCUS OBSERVING GEOMETRY



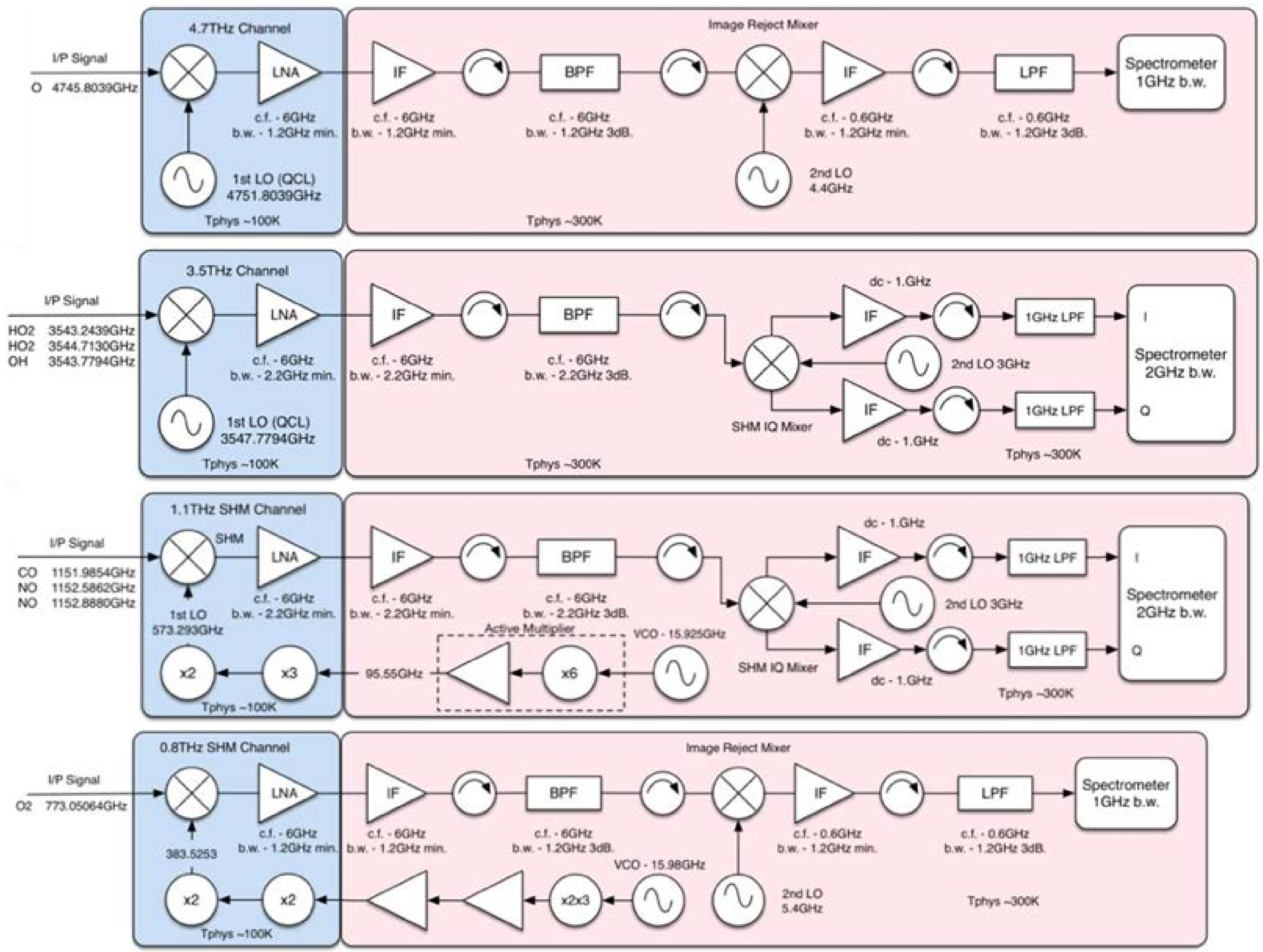
FOCAL PLANE AND QUASI-OPTICS



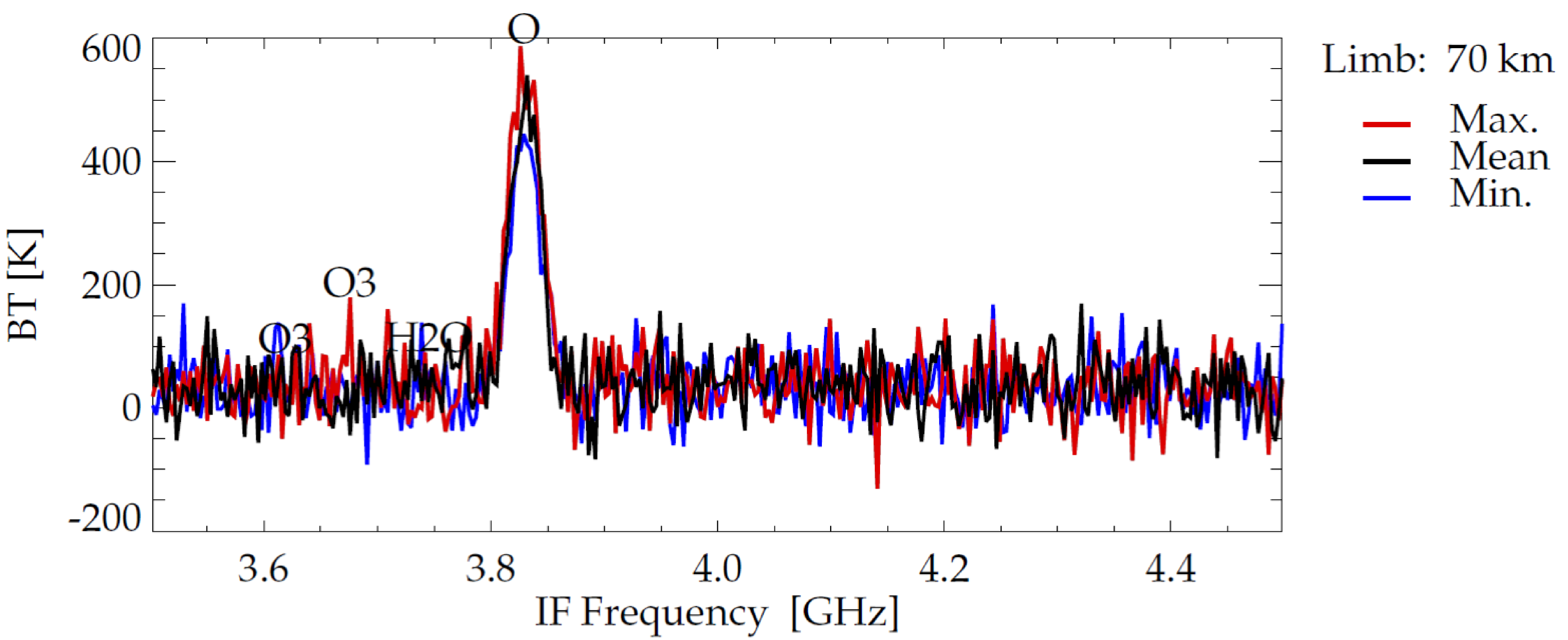




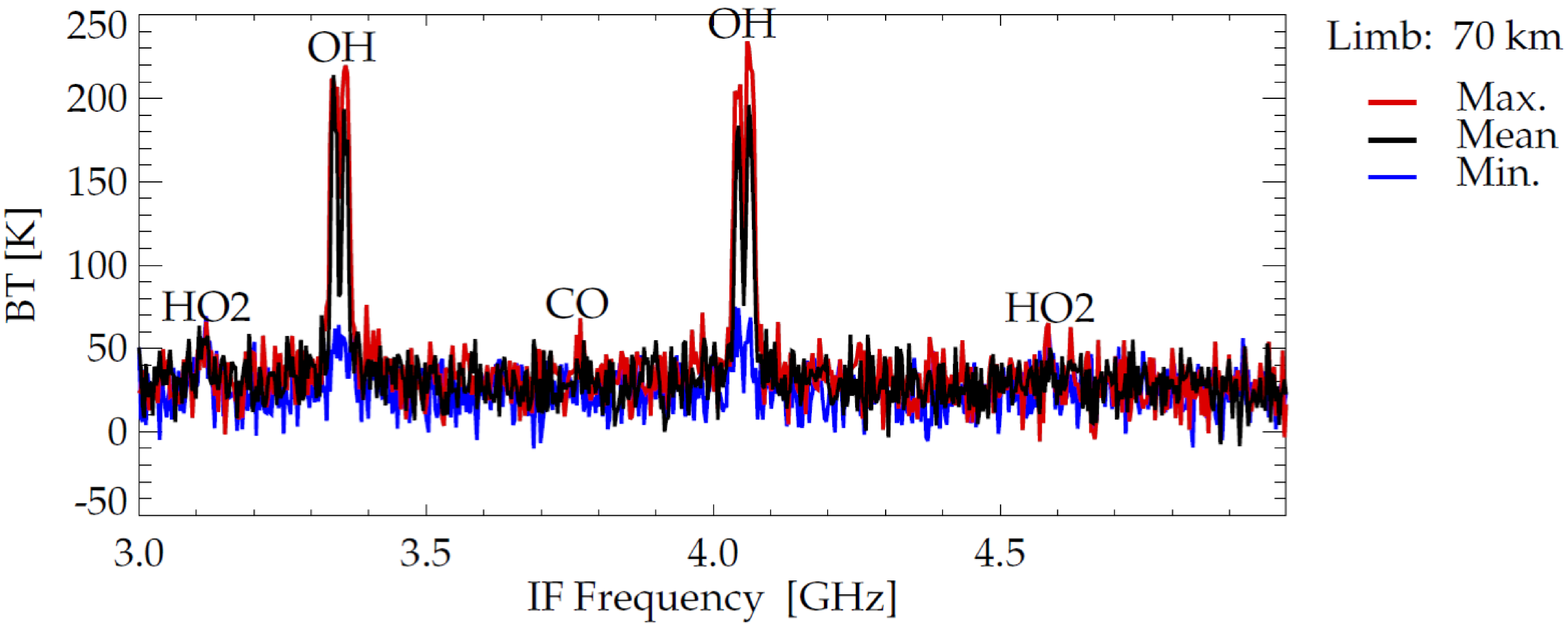
RADIOMETER CHANNEL DESIGN



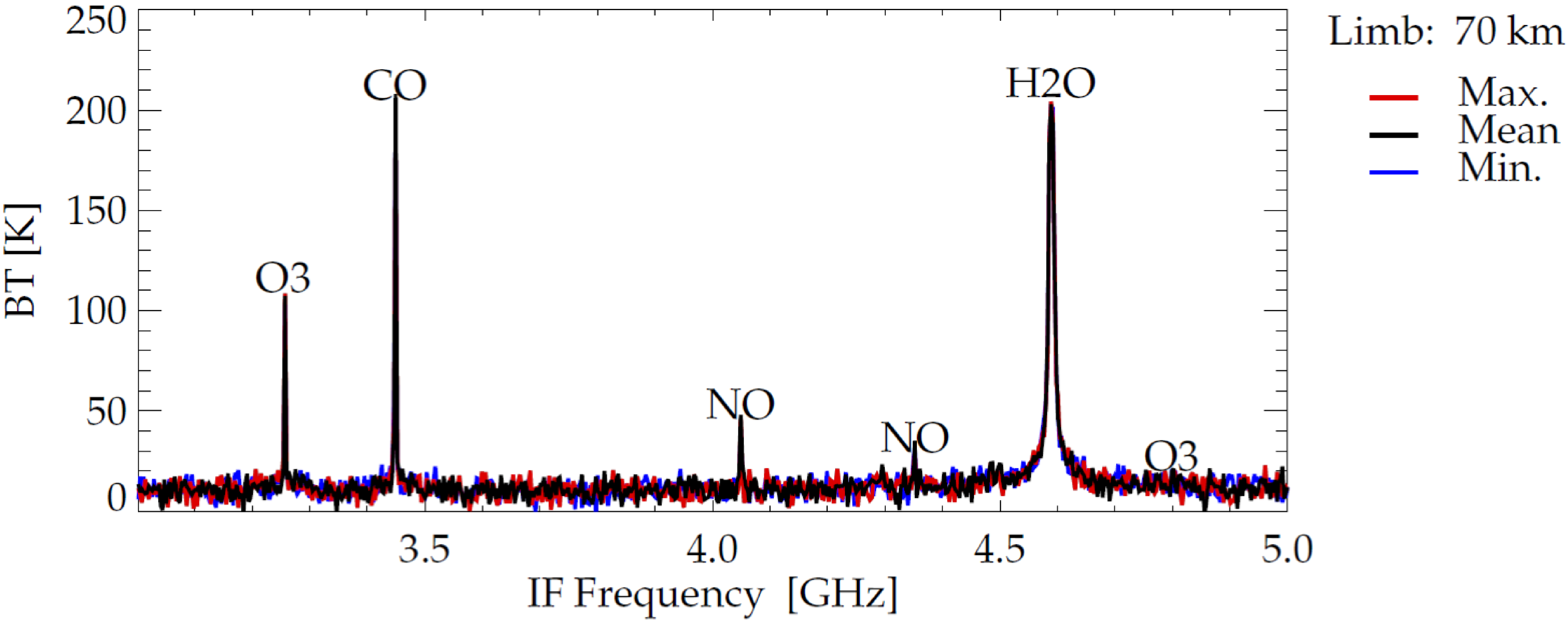
SPECTRAL SIMULATIONS - BAND 1 @ 4.7 THZ (NEDT = 46 K)



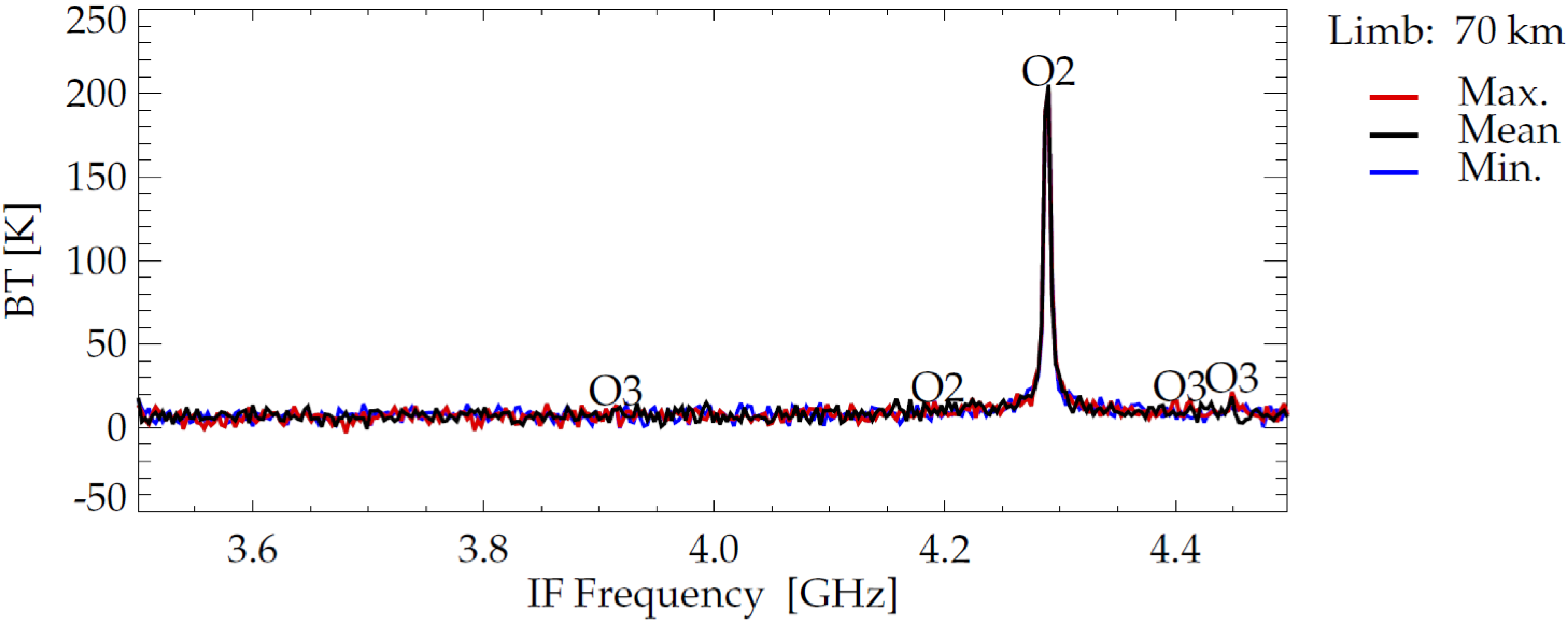
SPECTRAL SIMULATIONS - BAND 2 @ 3.5 THZ (NEDT = 12 K)



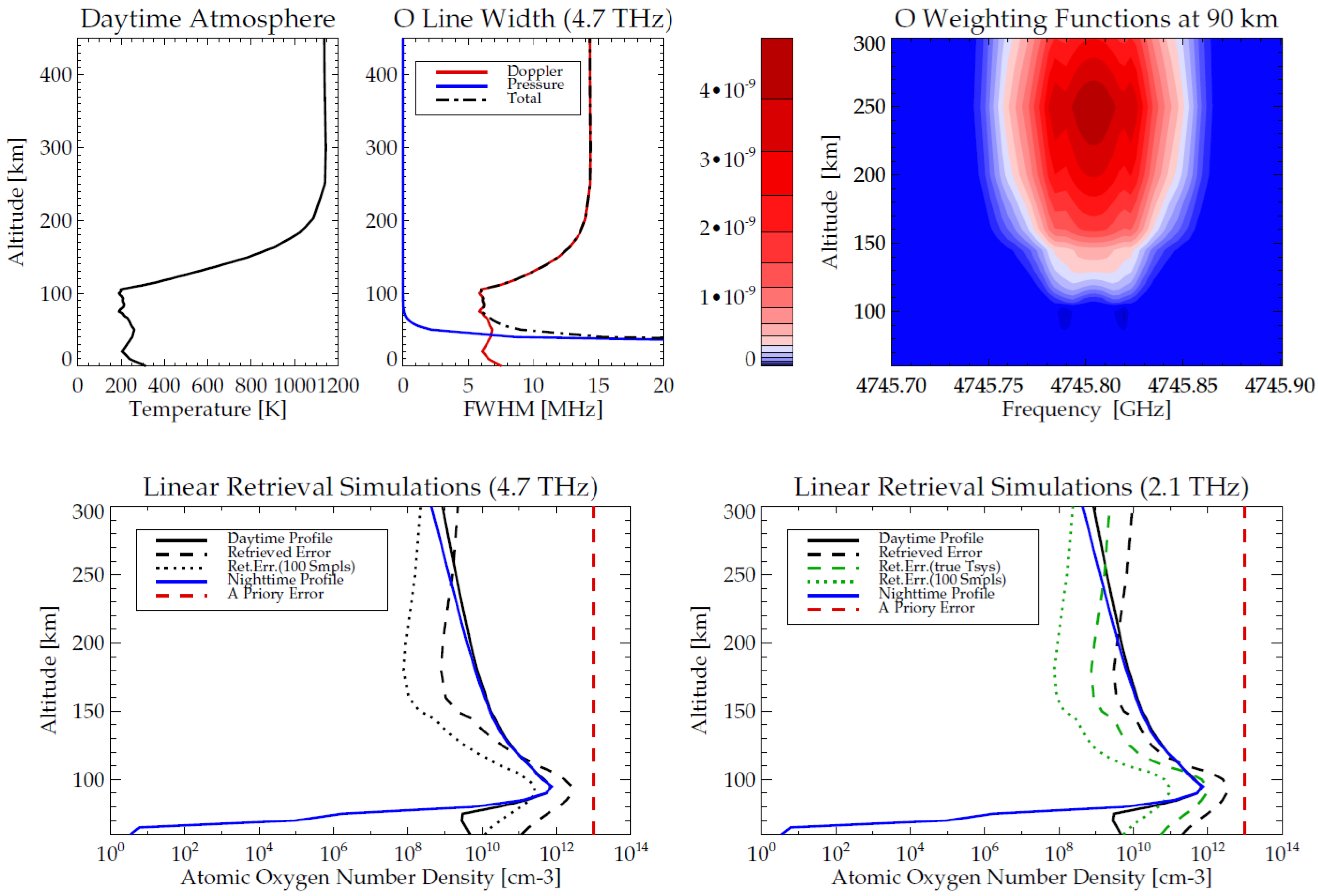
SPECTRAL SIMULATIONS - BAND 3 @ 1.14 THZ (NEDT = 4 K)



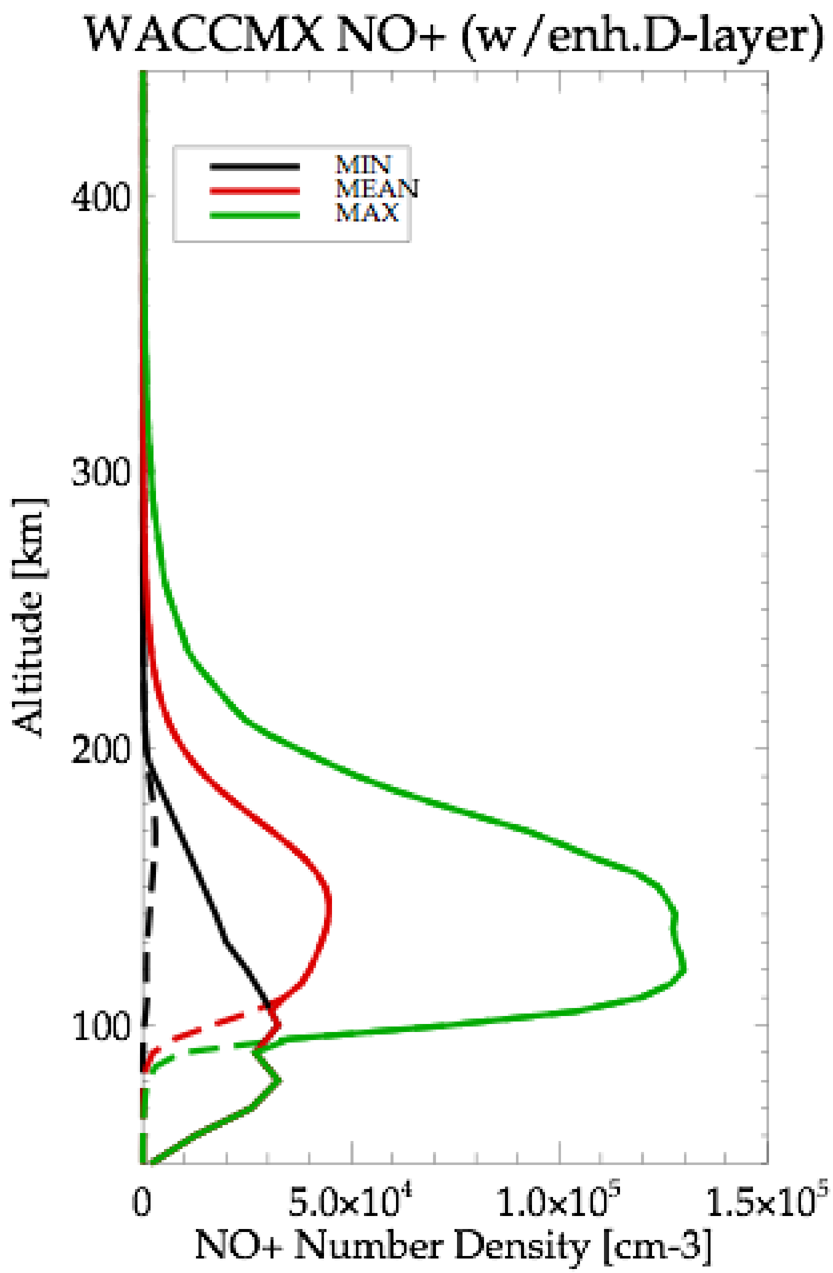
SPECTRAL SIMULATIONS - BAND 4 @ 0.8 THZ (NEDT = 3 K)

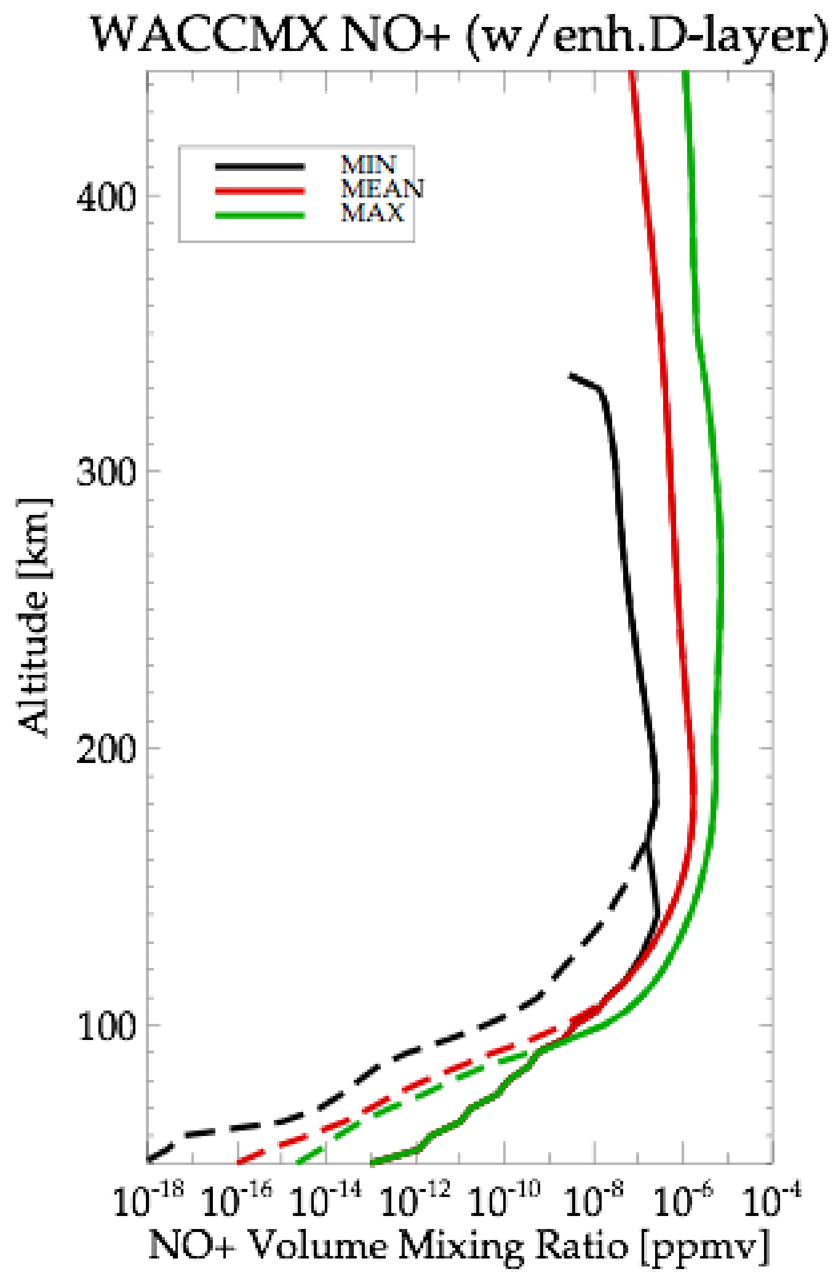


ATOMIC OXYGEN RETRIEVAL SIMULATIONS

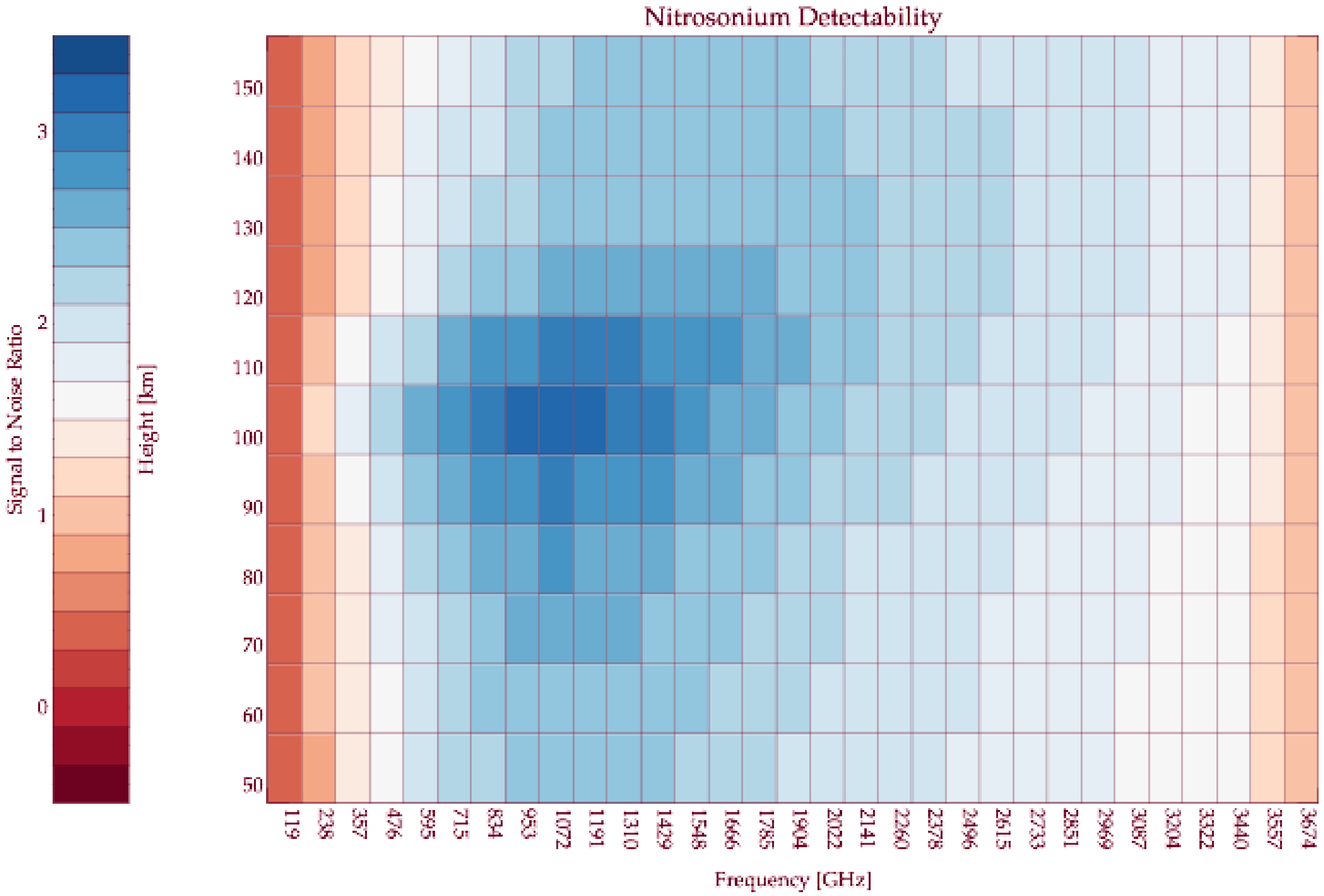


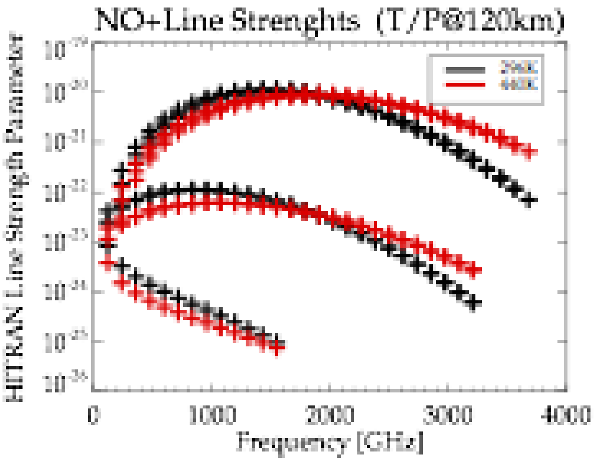
NITROSONIUM (NO^+) PROFILES

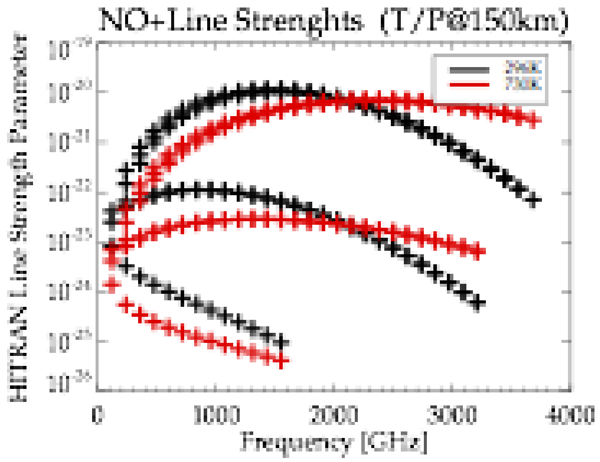


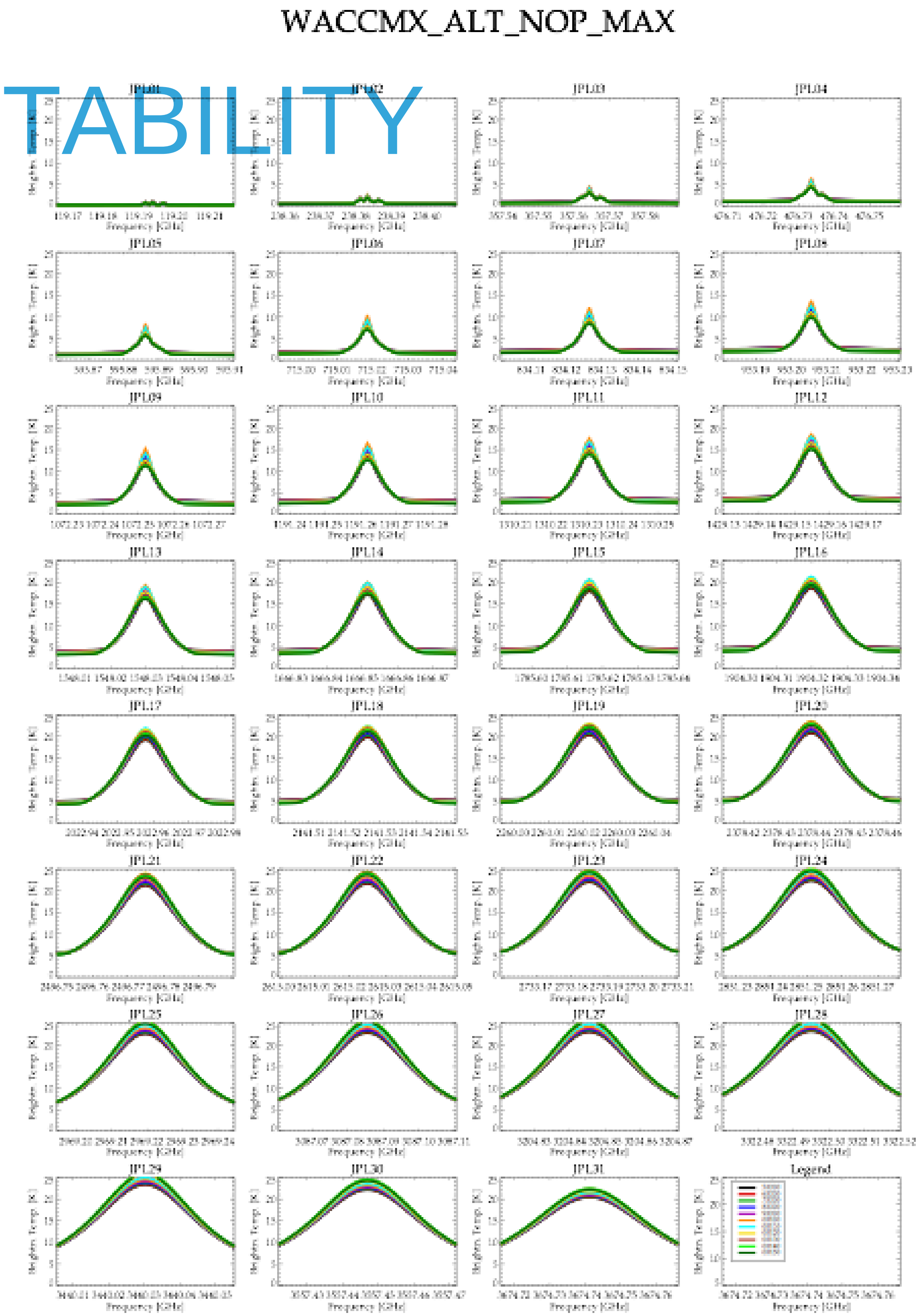


NITROSONIUM DETECTABILITY









LOCUS PROGRAMME SCHEDULE

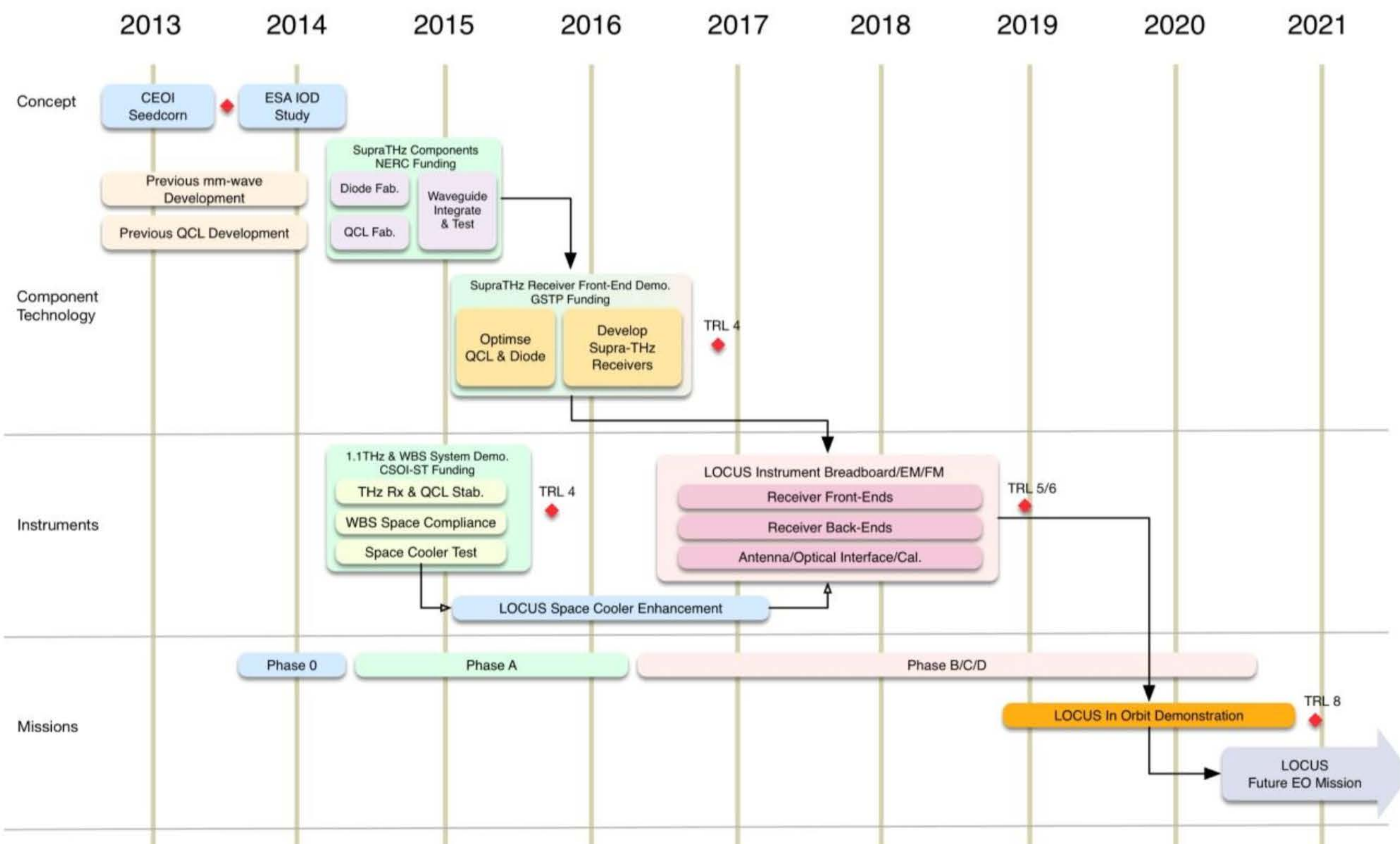


Figure 8-14: LOCUS radiometer technical development roadmap

SABER METHOD FOR INDIRECT DETECTION OF ATOMIC OXYGEN

- Daytime: k2 [O][O2][M] = J[O3]
- Measure [O3] @ 9.6 um, calculate [O2] from pressure and temperature using ideal gas law, assume k2
- Nighttime: k4[H][O3] = k2 [O][O2][M]
- Measure [OH] @ 2 um to determine the reaction rate of [H] and [O3] recombination, assume this balances out the [O3] loss from [O].